(54) **Film thickness controller**

Steuergerät für die Dicke einer Schicht

Appareil de commande de l'epaisseur d'une couche

(72) Inventor: **Akasaka, Noriyuki**
c/o Nagoya Technical Institute
Nakamura-ku, Nagoya, Aichi Pref. (JP)

Description

Field of the invention and related art statement

5   **[0001]** The present invention relates to a film thickness controller and a method for controlling the thickness of a film for use in an extrusion molding apparatus and in a flowing type molding apparatus such as a film or sheet manufacturing apparatus.

  [0002] A conventional film thickness controller is now described briefly.

  [0003] An extrusion molding apparatus for manufacturing film or sheet is required to manufacture a molded product
10   such as film or sheet having thickness maintained to a predetermined value. An example of a conventional apparatus having a die provided with an adjusting mechanism which can adjust thickness of film along the width thereof is now described with reference to Figs. 7 to 9. Molten plastic is fed from an extruder 1b (Fig. 7) to a die 2b. The molten plastic is expanded in a manifold 3b in the width direction perpendicular to paper of Fig. 7 showing the die 2b and flows down from a slit-shaped outlet 5b of die lips 4b. Then, the molten plastic flowing down from the outlet 5b is cooled by a cooling
15   roller 6b and solidified to be film 7b so that the film is wound on a winder 10b.

  [0004] A thickness gauge 11b measures thickness of the film 7b. The thickness gauge 11b utilizes radiation due to the natural disintegration of radioactive substance to measure thickness of the film 7b in accordance with degree of reduction of the radiation intensity when the radiation passes through the film 7b. The thickness gauge includes a single detection element which is moved in the reciprocating manner along the width of the film 7b to measure thickness
20   of the film 7b along the width.

  [0005] It is required that the thickness of the film 7b is maintained to be a predetermined thickness along the width. However, since it is difficult that molten plastic passes through a narrow gap of the die 2b in the same speed along the width, the thickness of the film 7b is not necessarily identical along the width thereof.

  [0006] Accordingly, thickness adjusting mechanisms 12b which serve to change a discharge amount of molten plastic
25   along the length of the slot of the die lips 4b are disposed dispersedly along the length of the slot of the die lips 4b. As the thickness adjusting mechanism 12b, there are the following types, for example:

    (1) Heater type: A multiplicity of heaters are embedded in the die lips 4b along the length of the slot of the die lips 4b and are controlled to change a temperature generated therefrom so that the viscosity of the molten plastic
30   therein is changed and the flowing speed of the molten plastic is changed to control the discharge amount of the molten plastic.

    (2) Bolt type: A multiplicity of screws are disposed along the length of the slot of the die lips 4b to change a gap space of the discharge outlet 5b of the slot of the die lips 4b mechanically or thermally or electrically so that the discharge amount of the molten plastic is controlled.

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  [0007] Accordingly, the thickness of the film 7b can be automatically controlled by adjustment of the thickness adjusting mechanism 12b.

  [0008] Fig. 9 is a block diagram of a conventional thickness controller for one operating terminal device of the thickness adjusting mechanism 12b. A controller 13b is supplied with a difference between a thickness $\underline{b}$ of a portion of the
40   film measured by the thickness gauge 11b and a set value $\underline{a}$ of thickness. The controller 13b calculates an amount of operation for the adjusting mechanism 12b corresponding to the portion of the film measured by the thickness gauge 11b and supplies it to the adjusting mechanism 12b. When the mechanism 12b is operated, a discharge amount of molten plastic in the die lips 4b is changed and thickness of the portion of the film controlled by the mechanism 12b is changed to effect the thickness control. The thickness control over the whole width of the film can be made by provision
45   of the number of the control loop blocks of Fig. 9 corresponding to the number of places in which the thickness control is performed.

  [0009] The conventional film thickness controller as described above has drawbacks as follows:

    (1) There is a dead time L_1 due to movement of the film from the outlet of the die to the thickness gauge 10 until
50   variation of thickness of the film is detected by the thickness gauge 10 after the variation has been produced at the outlet of the die.

    (2) When an operating terminal device of the die lip adjusting mechanism corresponding to a portion of the film is controlled, there occurs an interference phenomenon that thickness of an adjacent portion of the film to the operating terminal device of the adjusting mechanism is changed.
55   (3) In order to minimize the interference effect to the film thickness due to mutual interference of the operating terminal device of the lip adjusting mechanism described in (2), there is a control system which updates commands of the operation amount for a multiplicity of operating terminal devices simultaneously. The control system performs a calculation each time a thickness gauge which is reciprocated along the width of the film reaches an end of the

film in which the thickness gauge completes reading of thickness data of the film along the width thereof. Consequently, an operation until the thickness gauge reaches the end of the film after the thickness gauge has measured thickness of a portion of the film takes a time, which is a dead time L_2 until the control system starts the calculation actually after the thickness data has been obtained. Accordingly, a dead time after the operation amount for the operating terminal device has been changed and its influence has been detected as a thickness data until the detected thickness data is employed to perform the calculation is a sum of the dead time L_1 described in (1) and the dead time L_2 described above.

[0010]   As described above, the conventional film thickness controller has (A) a first drawback of producing a large dead time and (B) a second drawback of generating the interference effect. Description is now made to problems due to these drawbacks.

A. Problem due to large dead time:

[0011]   Since there is a large phase delay due to the dead time, a gain of a controller can not be increased even if phase compensation is effected in order to attain stability in the control system. Accordingly, the high-speed response and the steady-state accuracy of the control system are deteriorated. Further, the thickness of the film is always influenced by an external disturbance due to variation of an adjacent die lip adjusting mechanism.

B. Problem due to interference effect:

[0012]   In Fig. 9, when an operating terminal device of a portion of the conventional adjusting mechanism 12b is operated, the thickness of a portion of the film corresponding to an adjacent operating terminal device is changed. Accordingly, the operating terminal device of the portion of the adjusting mechanism and the control loop for controlling thickness of a portion of film corresponding to the position of the operating terminal device interfere with each other. Consequently, the following problems occur:

(1) Even if the stability of the control loop shown in Fig. 9 is ensured, since operation of an operating terminal device of the adjusting mechanism 12b is influenced by the control loop which controls thickness of the film corresponding to an adjacent operating terminal device, the control loops interfere with each other and the stability of the whole control system is not ensured when the thickness of the film is controlled over the whole width of the film. Accordingly, in order to eliminate the influence of the mutual interference, the gain of the controller 13b is reduced so that the control system has a low-speed response.
(2) Conversely, when it is considered to design a stable control system constituting a multi-variable system in consideration of the mutual interference between the operating terminal devices of the adjusting mechanism 12b, the control system becomes a very large system since a hundred or more operating terminal devices are usually disposed in the longitudinal direction of the slot of the die lips 4b and there are detected values of the film thickness equal to the number of the operating terminal devices. Accordingly, it is difficult to design such a large system with ensured stability.

Object and Summary of the invention

[0013]   It is an object of the present invention to provide a method and a film thickness controller which solve the problems due to the interference effect in a film thickness controller having a die lip adjusting mechanism with interference effect by combining a plurality of basic control systems.

[0014]   This object is achieved by a controlling method having the features of claim 1 and a film thickness controller having the features of claim 2.

Fig. 1 is a block diagram showing a configuration of a controller of a first embodiment of the invention;
Fig. 2 is a block diagram expressing a dynamic mathematical model of a film thickness manufacturing process of the first embodiment of the invention;
Fig. 3 is a block diagram showing a configuration of a basic controller of the embodiment;
Fig. 4 illustrates an application procedure of the basic control system of Fig. 3 to thickness control points;
Fig. 5 illustrates a correspondence of positions of five arbitrary operating terminal devices and five thickness detection positions of the embodiment;
Fig. 6 illustrates a locus of a thickness gauge which is reciprocated to detect thickness of film in the embodiment;
Fig. 7 schematically illustrates a configuration of a conventional film manufacturing plant;
Fig. 8 illustrates an arrangement of operating terminal devices embedded in a die of Fig. 7;

Fig. 9 is a block diagram showing a configuration of the conventional film thickness controller;

Figs. 10(a) to 13(a) are graphs showing simulation results of the embodiment when a set value of thickness is changed and Figs. 10(b) to 13(b) are graphs showing simulation results of the embodiment when external heat is added to a heater;

Fig. 14 illustrates a discrete time for determining a gain matrix of an operational calculator of the second embodiment; and

Figs. 15(a) to 17(a) are graphs showing simulation results of the second embodiment when a set value of thickness is changed, and Figs. 15(b) to 17(b) are graphs showing simulation results of the second embodiment when external heat is added to a heater.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

First Embodiment of the Invention

(a) Basic Configuration

[0015]   The first embodiment of the invention is described with respect to Figs. 1 to 6.

[0016]   Fig. 1 is a block diagram of a film thickness controller for controlling heater and corresponding to a conventional adjusting mechanism 12b (Fig. 7). An output of a thickness gauge 11b is connected to a thickness data memory 110. An arrival end identification output signal d from the thickness gauge 11b is connected to a distributor 111 and a basic control system 112-i (i=1-N). A plurality of outputs of the distributor 111 are connected to their corresponding basic control systems 112-i, respectively. Each of outputs of the basic control system 112-i is connected to each of their corresponding command memories 113-i for heat generated by the heaters. Each of outputs of the command memories 113-i is connected to superposition adder 114. An output of the adder 114 is connected to an operation value memory 115. An output of the memory 115 is connected back to the basic control systems 112-i.

(b) Basic Control system

[0017]   Operation of one operating terminal device of the adjusting mechanism for die lips changes thickness of a portion of film corresponding to an adjacent operating terminal device thereto. However, since the interference range thereof is limited, there is considered the basic control system including operating terminal devices disposed around a certain operating terminal device and disposed corresponding to portions of film of which thickness is changed by operation of the certain operating terminal device. The basic control system can control only thickness of a portion of film corresponding to the operating terminal device selected as a center to a predetermined value of thickness. More particularly, the basic control system Can maintain the thickness of a portion of film corresponding to the certain operating terminal device to the predetermined value of thickness by varying operation values of not only the certain operating terminal device but also adjacent operating terminal devices. The basic control system takes small number of the operating terminal devices and interference to thickness of film between operating terminal devices into consideration. A control system having small number of operating terminal devices and having the following merits is hereinafter referred to as a basic control system.

(i) Stability of the control system can be ensured because of small number of operating terminal devices, and the control system having a high-speed response can be designed.

(ii) The control system which can control thickness of a portion of film corresponding to a central operating terminal device to the predetermined value to compensate external disturbance even if external disturbance is applied to the central operating terminal device as well as the adjacent operating terminal device can be designed.

(iii) Since interference to thickness of film between operating terminal devices is considered, the control system which can effectively distribute operation values to operating terminal devices including adjacent operating terminal devices to change thickness of a portion of film corresponding to the central operating terminal device can be designed. That is, variation of the operation value of the central operating terminal device is large, while variation of the operation value of the adjacent operating terminal device is smaller as influence thereof to thickness of film is smaller.

(c) Variation of Operation Value in Adjacent Operating Terminal device as External Disturbance

[0018]   In order to control thickness of the film over the whole width thereof stably with a high-speed response, the above basic control system is applied to each of operating terminal devices of the adjusting mechanism. Thus, the stability of thickness control of the whole film is ensured as follows.

(i) In a basic control system i' for a certain operating terminal device i, thickness of a portion of film corresponding to the operating terminal device is ensured to be controlled to the predetermined value even if external disturbance is added to the adjacent operating terminal device. When a basic control system (i+1)' is applied to an operation unit i+1 adjacent to the operation unit i, thickness of a portion of film corresponding to the operating terminal device i+1 is ensured to be controlled to the predetermined value stably.

(ii) The basic control system i' applied to the operating terminal device i can consider the operation value command in the basic control system (i+1)' applied to the operating terminal device i+1 as an external disturbance applied to the operating terminal device of the basic control system i'.

[0019]   As described in the above item (b), the basic control system can stably control thickness of a portion of film corresponding to the operating terminal device i to which the basic control system i' is applied to compensate external disturbance even if external disturbance is added to the operating terminal device in the basic control system. Accordingly, thickness of a portion of film corresponding to the operating terminal device i can be controlled stably even if another basic control system is applied to the operating terminal device i+1.

(d) Dead Time

[0020]   In order to minimize interference effect to film thickness due to mutual interference of the operating terminal devices of the adjusting mechanism 12b to control thickness of film over the whole width thereof, there is considered a control system which updates operation value commands for a multiplicity of operating terminal devices simultaneously. To this end, it is necessary to move a thickness gauge in reciprocating manner along width of film to obtain all data of thickness along the width of film and perform calculation each time the thickness gauge reaches an end of film. In this case, the thickness gauge requires time to reach an end of film after measured thickness of a certain portion of film. This time is a dead time until the calculation is actually started after thickness data has been obtained. Accordingly, the dead time from after an operation value in the operating terminal device has been changed until thickness of film influenced by the change of the operation value has been detected as a thickness data and the detected thickness data is employed to perform calculation is a sum of a dead time L_1 due to movement of film from the die lips to the thickness gauge and the above mentioned dead time L_2. That is, the dead time L of the equation (3b) is expressed by

$$L = L_1 + L_2 \qquad (4b)$$

The thickness gauge measures thickness of film while being moved in reciprocating manner along the width of film. Since the film is moved at a certain speed, the thickness gauge measures thickness of film along a locus as shown in Fig. 6. If a position of a portion of film having thickness t3 is indicated by a point ⓒ in Fig. 6, the dead time L_2 due to movement of the thickness gauge in the case where calculation is made at an end Ⓐ of film is expressed by a time L_2' of movement of the thickness gauge between the points Ⓐ and ⓒ in Fig. 6.

[0021]   On the other hand, when calculation is made at an end Ⓑ of film, the dead time L_2 due to movement of the thickness gauge is expressed by a time L_2'' of movement of the thickness gauge between the points ⓒ' and Ⓑ in Fig. 6. As seen from Fig. 6, since the dead times L_2' and L_2'' are generally different from each other, the control system for controlling thickness t3 to a predetermined value is characterized in that the dead time L is different depending on whether the calculation is made at the end Ⓐ or Ⓑ. Accordingly, the thickness gauge produces an arrival end identification signal for identifying whether the thickness gauge reaches the end Ⓐ or Ⓑ.

(e) Transfer Function Matrix

[0022]   A basic control system is considered and this basic control system has five heaters h1 to h5 as operating terminal devices which are controlled by the basic control system, the five heaters being disposed in a longitudinal direction of a slot formed between the die lips. The basic control system 112-i can control thickness of a portion of film corresponding to a central heater h3 to a predetermined value even if external disturbance is added to the heaters h1 to h5. The reason that adjacent heaters h1, h2 and h4, h5 are taken into consideration in addition of the central heater h3 is because there is interference that heat generated by the heater h3 changes thicknesses t1, t2 and t4, t5 of film corresponding to the heaters h1, h2 and h4, h5 and influence to the heaters disposed outside of the heaters h1 and h5 by heat generated by the heater h3 is negligible. Accordingly, control object for designing the basic control system is expressed by the transfer function matrix G(s) of the following equation (lb):

$$
\begin{pmatrix} Y_1(s) \\ Y_2(s) \\ Y_3(s) \\ Y_4(s) \\ Y_5(s) \end{pmatrix} = \begin{bmatrix} g_1(s) & g_2(s) & g_3(s) & 0 & 0 \\ g_2(s) & g_1(s) & g_2(s) & g_3(s) & 0 \\ g_3(s) & g_2(s) & g_1(s) & g_2(s) & g_3(s) \\ 0 & g_3(s) & g_2(s) & g_1(s) & g_2(s) \\ 0 & 0 & g_3(s) & g_2(s) & g_1(s) \end{bmatrix} \begin{pmatrix} U_1(s) \\ U_2(s) \\ U_3(s) \\ U_4(s) \\ U_5(s) \end{pmatrix} \tag{1b}
$$

$$
\parallel
$$

$$
G(s)
$$

where $U_1(s)$ to $U_5(s)$ are Laplace transformed values of heat $U_1(t)$ to $U_5(t)$ generated by the heaters hl to h5, $Y_1(s)$ to $Y_5(s)$ are Laplace transformed values of thicknesses $y_1(t)$ to $y_5(t)$ of portions corresponding to the heaters h1 to h5, and $g_1(s)$ to $g_3(s)$ are transfer functions corresponding to respective inputs and outputs. For example, $g_1'(s)$ is a transfer function which produces temporal variation of thickness t3 when only the heater t3 is changed. In the transfer function matrix G(s) of the equation (1b), non-diagonal terms express mutual interference to thickness between heaters.

(e) State Equation

[0023] In order to express the relation between the inputs Ui(s) and the outputs Yi(s) (i=1-5) of the equation (1b), the following equation convenient for design of the control system is employed.

$$
X(t) = Ax(t) + Bu(t) \tag{2b}
$$

$$
y(t) = Cx(t-L) \tag{3b}
$$

where X is a state vector, u is an input vector in which $u(t)=[u_1(t),\ u_2(t),\ u_3(t),\ u_4(t),\ u_5(t)]^T$ (where T expresses transposition), y is an output vector in which $y(t)=[y_1(t),\ y_2(t),\ y_3(t),\ y_4(t),\ y_5(t)]^T$, L of the equation (3b) is the dead time.
[0024] The equations (2b) and (3b) are controllable and observable. The relation of the input u(t) and the output y (t) is expressed as in Fig. 23 from the equations (2b) and (3b). Double line of Fig. 2 indicates a vector value.

(f) Basic Control System as Solution of State Equation

[0025] In the first embodiment of the invention, the basic control system as a solution of the state equation is the control system described in detail in the first embodiment of the invention of EP 0608918.
[0026] Description is made to the basic control system in which operation amounts of the five heaters h1 to h5 around the heater h3 influence the output y_3 of the thickness gauge corresponding to the heater h3.
[0027] The basic control system satisfies the following conditions.

(1) Thickness y3 (hereinafter yi(t) is described as yi) is controlled to a predetermined value with good response even if external disturbance is added to the heaters h1 to h5.
(2) In order to control thickness y3, operation amounts are assigned to the heaters so that variation of operation amount in the heater h3 is largest, variation in the heaters h2 and h4 is largest next to the heater h3, and variation in the heaters h1 and h5 is smallest.

[0028] The basic control system satisfying the above conditions can be realized by the control system having the configuration shown in Fig. 3.
[0029] Operation of the basic control system of Fig. 3 is described. The thickness gauge detects thickness while being moved in reciprocating manner along the width of film. When the gauge reaches the end Ⓐ or Ⓑ of film, measurement of thickness of film along the width thereof is completed. At this time the calculation is performed and accordingly the execution period T of the calculation is substantially equal to a time required for movement of the thickness

gauge along the width and is considered to be constant. Accordingly, the basic control system is a discrete time control system.

(g) Operation of Basic Control System

[0030] Operational procedure of the basic control system of Figurs 3 and 6 is as follows:

(1) It is assumed that the thickness gauge 11b reaches the end ⒶorⒷof film at the discrete time $t=_{k+1}$. At this time, a vector consisting of detected values of thickness $y(t_{k+1})=y(k+1)(y_1(k+1)\sim y_5(k+1)$ is obtained through the thickness gauge 11b and sampler 100. At the same time, the thickness gauge produces the arrival end identification signal d indicative of the end which the gauge has reached.

(2) Only thickness $y_3(k+1)$ of a portion of film corresponding to the heater h3, of the film thickness detection vector $y(k+1)$ is supplied to a subtracter 101 which produces thickness deviation $\varepsilon (k+1)=r_3(k+1)-y_3(k+1)$ between the thickness $y_3(k+1)$ and a set value $r_3(k+1)$.

(3) An integrator 102 is supplied with the thickness deviation $\varepsilon (k+1)$ from the subtracter 101 and produces a time-integrated value $X_r(k+1)$ of the thickness deviation. The integrator 102 serves as an external disturbance compensator to compensate the external disturbance varying thickness y_3 by heat generated by the heater and to control thickness y_3 to be identical with a set value.

(4) The operational calculator 103 is supplied with a past time sequence data (herein u(k)) of heat generated by the heater stored in a memory 104 and the film thickness detection value y(k+1) and produces an estimated value $\hat{X}(t_{k+1}-L)=\hat{\omega} (k+1)$ of state variable at time $(t_{k+1}-L)$ before time t_{k+1} by the dead time L defined by the arrival end identification signal d produced from the thickness gauge.

(5) A state shifter 105 is supplied with the output $x_r(k+1)$ of the integrator 102 and the output $\omega (k+1)$ of the operational calculator 103 and multiplies them by a coefficient for shifting the state by the dead time L defined by the arrival end identification signal d produced by the thickness gauge to obtain a state estimated value at time t_{k+1}.

(6) A state prediction device 106 produces state variations for the inputs u(k) from time $(t_{k+1}-L)$ to time t_{t+1} which are supplied from the memory 104 which stores the past time sequence data of heat generated by the heater by the dead time defined by the arrival end identification signal d produced by the thickness gauge.

(7) An adder 107 is supplied with an output of the state shifter 105 and an output of the stage prediction device 106 and produces as the addition result thereof a state estimated value at time t_{k+1}. Although the operational calculator 103 can not obtain only the state estimated value at time $(t_{k+1}-L)$ due to the dead time L, the state shifter 105 and the state prediction device 106 effect integration operation during the dead time L to obtain the state estimated value at time t_{k+1}. Since the above operation (5), (6) and (7) can remove influence of the phase delay due to the dead time L, thickness control with good response can be effected while maintaining the stability of the control system.

(8) A heat commander 108 multiplies the state estimated value from the adder 107 by the feedback gain to produce a heat command value to the operating terminal device 109. If the operation amount of the operating terminal device 109 is changed, thickness of the film is changed through thickness process 130

(9) The above calculation is made each time a new film thickness detection value y(k+2) is obtained by the sampler 100 when the thickness gauge 11b reaches the opposite end of film at time t_{k+2} and thickness data along the whole width of the film is newly obtained through the dead time 131.

(h) Thickness Control by Combined Basic Control Systems

[0031] The application procedure obtained as described above is shown in Fig. 4.
[0032] Fig. 4(a) illustrates the application of the basic control system (1) in order to control thickness y_3 to a predetermined value. The basic control system (1) detects thicknesses y_1 to y_5 and defines command values $u_1^{(1)}$ to $u_5^{(1)}$ of heat generated by the heaters corresponding to the thicknesses y_1 to y_5.
[0033] Fig. 4(b) illustrates the application of the basic control system (2) in order to control thickness y_4 to a predetermined value. The basic control system (2) detects thicknesses y_2 to y_6 and defines command values $u_2^{(2)}$ to $u_6^{(2)}$

of heat generated by the heaters corresponding to the thicknesses y_2 to y_6.

[0034] Fig. 4(c) illustrates the application of the basic control system (3) in order to control thickness y_5 to a predetermined value. The basic control system (3) detects thicknesses y_3 to y_7 and defines command values $u_3^{(3)}$ to $u_7^{(3)}$ of heat generated by the heaters corresponding to the thicknesses y_3 to y_7.

[0035] Fig. 4(d) illustrates the application of the basic control system (4) in order to control thickness y_6 to a predetermined value. The basic control system (4) detects thicknesses y_4 to y_6 and defines command values $u_4^{(4)}$ to $u_8^{(4)}$ of heat generated by the heaters corresponding to the thicknesses y_4 to y_8.

[0036] Fig. 4(e) illustrates the application of the basic control system (5) in order to control thickness y_7 to a predetermined value. The basic control system (5) detects thicknesses y_5 to y_9 and defines command values $u_5^{(5)}$ to $u_9^{(5)}$ of heat generated by the heaters corresponding to the thicknesses y_5 to y_9.

[0037] The final command value u_5 for the heater h5, for example, is given by the following equation from the above basic control systems (1) to (5).

$$u_5 = (u_5^{(1)} + u_5^{(2)} + u_6^{(3)} + u_5^{(4)} + u_5^{(5)}) \times 1/5 \qquad (4b)$$

As described above, the command value of heat generated by one heater h5 is defined by application of five basic control systems.

(i) Stability of Thickness Control by Combined Basic Control Systems

[0038] Referring to Fig. 4, description is now made to operation that the basic control systems are successively applied to control thickness of a portion of film corresponding to each of the operating terminal devices, that is, the heaters to the predetermined value so that thickness control of the whole film is made stably with good response.

[0039] The basic control system (3) which controls thickness y_5 of a portion of film corresponding to the heater u_5 to a predetermined value is taken as an example. Since the command value of heat generated by the heater h(3) is given by an averaged addition value $(u_3^{(3)} + u_3^{(1)} + u_3^{(2)}) \times 1/3$ of the command values $u_3^{(3)}$, $u_3^{(1)}$ and $u_3^{(2)}$ of the basic control systems (3), (1) and (2), respectively, it is considered that the heater h3 is influenced by a kind of external heat of $(u_3^{(1)} + u_3^{(2)}) \times 1/3$. Then, since the command value of heat generated by the heater h4 is given by an averaged addition value $(u_4^{(3)} + u_4^{(1)} + u_4^{(2)} + u_4^{(4)}) \times 1/4$ of the command values $u_4^{(3)}$, $u^{4(1)}$, $u_4^{(2)}$ and $u_4^{(4)}$ of the basic control systems (3), (1), (2) and (4), respectively, it is considered that the heater h4 is influenced by external heat of $(u_4^{(1)} + u_4^{(2)} + u_4^{(4)}) \times 1/4$. Since the command value of heat generated by the heater h5 is given by an averaged addition value $(u_5^{(3)} + u_5^{(1)} + u_5^{(2)} + u_5^{(4)} + u_5^{(5)}) \times 1/5$ of the command values $u_5^{(3)}$, $u_5^{(1)}$, $u_5^{(2)}$, $u_5^{(4)}$, $u_5^{(5)}$ of the basic control systems (3), (1), (2), (4) and (5), respectively, it is considered that the heater h5 is influenced by external heat of $(u_5^{(1)} + u_5^{(2)} + u_5^{(4)} + u_5^{(5)}) \times 1/5$. The command value of heat generated by the heater h6 is considered to be influenced by external heat having an averaged addition value $(u_6^{(3)} + u_6^{(2)} + u_6^{(4)} + u_6^{(5)}) \times 1/4$ of the command values $u_6^{(3)}$, $u^{6(2)}$, $u_6^{(4)}$ and $u_6^{(5)}$ of the basic control systems (3), (2), (4) and (5), respectively. Finally, since the command value of heat generated by the heater h7 is given by an averaged addition value $(u_7^{(3)} + u_7^{(4)} + u_7^{(5)}) \times 1/3$ of the command values $u_7^{(3)}$, $u^{7(4)}$ and $u_7^{(5)}$ of the basic control systems (3), (4) and (5), respectively, it is considered that the heater h7 is influenced by external heat of $(u_7^{(4)} + u_7^{(5)}) \times 1/3$.

[0040] As described above, it is considered that all of the heaters of the basic control system (3) are influenced by external heat from the adjacent control systems. However, since the basic control systems (3) can control thickness y_5 to the predetermined value as described above even if external heat is added to the heaters 3 to 7, it is understood that control by the control basic device (3) to thickness y_5 is made stably. This can be applied to the other basic control systems which control thickness of other portions and accordingly it is understood that thickness control is stably made over the whole film.

(j) Configuration and Operation of Invention

[0041] Configuration of the invention is described with reference to Fig. 1.

[0042] Since the thickness gauge 11b is moved in reciprocating manner along the width of film to detect thickness of film, thickness data over the width of film is obtained each time the thickness gauge reaches the end of film. The thickness data over the width of film is supplied to the thickness data memory 110.

[0043] On the other hand, the thickness gauge 11b supplies the arrival end identification signal indicative of the end which the thickness gauge has reaches to the distributor 111 and the basic control systems 112-i (i=1-N) each time the thickness gauge has reached the end of film. When the distributor 111 is supplied with the arrival end identification signal from the thickness gauge IIb, the distributor 111 reads out a set of thickness data necessary for the basic control

systems 112-i from the thickness data memory 110 and supplies the set of thickness data to the predetermined basic control systems 112-i. Accordingly, the set of thickness data is simultaneously distributed to to the basic control systems which control thickness of portions of film corresponding to the heaters in synchronism with the arrival end identification signal. The basic control systems 112-i is supplied with the set of thickness data from the distributor 111 and data of the operation value memory and identifies the end of film which the thickness gauge has reached on the basis of the arrival end identification signal to select the correct dead time L and execute calculation so that a predetermined number of command values of heat are stored in the command value memories 113-2 to 113-N. When the command value memories 113-1 to 113-N are supplied with the command values of heat from all of the basic control systems 112-1 to 112-N, the superposition adder 114 adds outputs of the command value memories 113-1 to 113-N for each heater and calculates an average value thereof to define a final command value S of heat for each heater.

[0044] The command value S of the superposition adder 114 is stored in the operation value memory 115. Then, when the thickness gauge 11b has been moved and reached the opposite end of film so that a new arrival end identification signal has been produced, the distributor 111, the basic control systems 112-i (i=1-N) and the superposition adder 114 are all operated as described above so that all command values of heat are updated.

[0045] As described above, the basic control systems can control thickness of portions of film corresponding to the heaters to a predetermined value over the width of film stably.

(k) Example of Design

[0046] An example of design is described in the case where transfer functions $g_1(s)$, $g_2(s)$ and $g_3(s)$ are given by the following equations:

$$g_1(s) = \frac{0.044}{S^3 + 2.1S^2 + 2.6S + 0.05} \tag{5b}$$

$$g_2(s) = \frac{0.0009}{S^4 + 2.4S^3 + 2.7S^2 + 0.25S + 0.0015} \tag{6b}$$

$$g_3(s) = \frac{0.00002}{S^5 + 2.4S^4 + 2.8S^3 + 0.31S^2 + 0.0084S + 0.0004} \tag{7b}$$

The basic control systems (1) to (6) as shown in Fig. 4, ten heaters h1 to h10, and ten points t1 to t10 of thickness corresponding to positions of the heaters are assumed and it is considered that thicknesses y_3 to y_8 are controlled to a predetermined value. $u_i(t)(i=1-10)$ is variation (Kcal/s) of heat generated by the heater, and $y_i(t)(i=1-10)$ is variation (cm) of thickness of film at the position of the thickness gauge corresponding to the position of the heater. The dead time L_1 due to movement of the film and times L_2' and L_2'' (referred to Fig. 6) required for movement of the thickness gauge from the thickness control point 3 to 8 to the film end assume a value of the following equation and values' shown in Table 1.

L_1 = 30 seconds

Table 1.

Dead Time L at Thickness Control Points						
Thickness Control Point	3	4	5	6	7	8
Dead Time L_2''(sec)	1.5	2.25	3.0	3.75	4.5	5.25
Dead Time L_2''(sec)	15	14.25	13.5	12.75	12	11.25
Whole Dead Time L of End (A)(sec) (L_1+L_2)	31.5	32.5	33.0	33.7	34.5	35.25
The same of End (B)	45.0	44.25	43.5	42.75	42.0	41.25

It is assumed that the thickness control point 3 exists at the end Ⓐ of the film as shown in Fig. 6. The control calculation execution period T assumes the following value.

T = 16.5 seconds

In order to design the control system, it is necessary to express the relation between the input u(t) and the output y(t)

of the equation (1b) and obtain the controllable and observable state equations (2b) and (3b). G(s) constituted of g_1 (s), g_2(s) and g_3(s) of the equations (5b) to (7b) can be expressed by an equation of the 77th degree, while the controllable and observable equation has been found to be an equation of the 39th degree. Accordingly, the equations (2b) and (3b) of the 39th degree are obtained from G(s).

(1) Decision of State Feedback Gain Matrix

[0047] The state feedback gain matrix of the basic control system is obtained as a solution of an optimum regulator problem for the state equation extended to the equation of the 40th degree by introducing the integrator for compensation of external disturbance on the basis of the equation (2b). Since the calculation is made every T=16.5 seconds, the state equation of the continuous time system is changed to a discrete state function with the sampling period T=16.5 seconds and a regulator solution is applied. A proper estimation function is employed to obtain the state feedback gain matrix and as a result the following values are obtained as the eigen values of the control system.

$0.876 \pm 0.02i$, 0.79, $0.50 \pm 0.07i$, $0.60 \pm 0.09i$, $0.60 \pm 0.06i$, 0.51

Further, 30 eigen values other than above are not described since the absolute value thereof is less than 0.1 and attenuation is fast. Since all eigen values are within a circle having a radius of 1, stable control can be attained. Since the eigen value having the slowest attenuation is $0.88 \pm 0.02i$, the stabilization time Ts can be predicted as about 10 minutes from $(0876)^{35} \fallingdotseq 0.01$ with definition of control error 1% as follows.

Ts = Tx35 = 16.5x35 sec. = 577.5 sec. = 9.6 min.

(2) Decision of Feedback Gain of Operational Calculator

[0048] The feedback gain matrix of the operational calculator which estimates the state before time t_{k+1} for calculation execution by the dead time L is obtained for the state equation of the 39th degree and the output equation of the fifth degree. The gain matrix K is obtained as a solution of the optimum regulator problem using a proper estimation function. The following values are obtained as eigen values of the operational calculator for the obtained gain matrix.

$0.9077 \pm 0.0002i$, 0.9076, 0.9075, 0.9075, $0.772 \pm 0.0001i$, 0.722, 0.722, 0.722, $0.576 \pm 1x10^{-5}i$, $0.576 \pm 1x10^{-5}i$, 0.232, 0.232, 0.232, 0.232, 0.232

20 eigen values other than above concentrate to the origin. Since all the values are within a circle having a radius of 1, the estimated error can be reduced with the lapse of time. Since the eigen value having the slowest attenuation is 0.9077, the time To required for attenuation of the estimated error to an initial 1% can be predicted from $(0.9077)^{45} \fallingdotseq 0.01$ as follows.

To = Tx45 = 16.5x45 sec. = 742.5 sec. = 12.4 min.

(1) Simulation Example 1

[0049] Figs. 10 and 11 show an example of simulation result obtained by calculation using the state feedback and the gain of the operational calculation obtained above.

[0050] Figs. 10 and 11 show variations of thickness and variation of heat generated by the heaters when the set values of thickness y_3 to y_8 are changed stepwise by 0.02mm. Fig. 10(a) shows variations of five amounts y_1 to y_5 of thickness (variation of the detected value of the thickness gauge) versus time. Fig. 10(b) shows variations of heat u_1 to u_5 generated by the heaters at this time in the same manner as Fig. 10(a). Fig. 11(a) shows variations of thickness y_6 to y_{10} and Fig. 11(b) shows variations of heat u_6 to u_{10} generated by the heater.

[0051] Since calculation is made after the execution period of 16.5 seconds of calculation after the set value of thickness has been changed, variation of heat generated by the heater occurs after 16.5 seconds from change of the set value of thickness. An amount of heat generated by the heater is maintained to the same value until 16.5 seconds elapse and the next calculation is made. The calculation is made on the basis of a newly detected value of thickness after 16.5 seconds to change an amount of heat generated by the heater. Accordingly, an amount of heat generated by the heater changes stepwise as shown in Fig. 10 and 11(b).

[0052] On the other hand, variation of the detected thickness value is detected after the lapse of the dead time L after the amount of heat generated by the heater has been changed after the lapse of 16.5 seconds from the change of the set value. For example, when calculation is made with thickness y_3 for the end Ⓐ shown in Fig. 6 the dead time L is 31.5 seconds from Table 1. That is, variation of thickness is detected after the lapse of 16.5 + 31.5 = 48 seconds after the set value of thickness has been changed. Thickness y_3 is exactly changed to a set value as can be seen from Figs. 10 and 11. The heaters h1, h2, h9 and h10 are introduced in consideration of mutual interference to thicknesses y_3 and y_8 and the thicknesses y_1, y_2, y_9 and y_{10} corresponding to the heaters h1, h2, h9 and h10 are not controlled to the set value. On the other hand, variations of heat generated by the heaters u_3 and u_8 at the end in the thickness control region are largest, variations by the heaters u_4 to u_7 located in the center are largest next to the heaters u_3 and

u_8, and variations of the heaters u_1, u_2, u_9 and u_{10} located outside of the control region are smallest.

[0053] The stabilization time is about 18.5 minutes which is considerably large as compared with the stabilization time of 12.4 minutes calculated by the eigen value of the operational calculator (the stabilization time by the eigen value of the regulator is still shorter). This is based on the following reason.

[0054] In order to prevent the command value of heat generated by the heater from being changed largely for each calculation, the command value is defined with weight added as follows.

$$u_{d.k} = Wu_{d.k-1} + (1-W)u_k \qquad (8b)$$

where

$u_{d.k}$: command value of heat defined by the calculation time $t=t_k$,
$u_{d.k-1}$: command value of heat defined by the last calculation time $t=t_{k-1}$,
u_k: command value of heat calculated at the calculation time $t=t_k$, and
W: weight coefficient.

[0055] In this simulation, W=0.8. This means that when the calculation period T=16.5 seconds is considered, a time delay corresponding to a delay of first order having a time constant of 74.65 seconds is added to the heat commander. Accordingly, it is considered that the stabilization time of thickness control of Figs. 10, 11 is larger than the stabilization time estimated by the eigen value of the operational calculator. Then, even if the thickness control is in the stabilization state, the command value of heat changes for each calculation. The reason is because the magnitude of the dead time L in the calculation in the state shifter of the basic control system is different in one end Ⓐ and the other end Ⓑ of the film for calculation.

(m) Simulation 2

[0056] Figs. 12 and 13 shows a control result when external heat of 8.4 wattage is applied to the heater u_3 to u_8. Fig. 12(a) shows variations of thickness values y_1 to y_5 versus time, and Fig. 12(b) shows variations of heat u_1 to u_5 generated by the heaters versus time. Fig. 13(a) shows variations of thickness values y_6 to y_{10} versus time and Fig. 13(b) shows variations of heat u_6 to u_{10} generated by the heaters versus time.

[0057] As can be seen in Figs. 12 and 13(a), although the thickness values y_3 to y_8 are once increased by the external heat of the heater u_3 to u_8, the thickness values y_3 to y_8 are returned to the original set value by changing the amounts of heat generated by the heaters u_1 to u_{10} and the stabilization time is about 18.5 minutes in the same manner as Figs. 10 and 12. It is understood that variation due to the external disturbance is exactly compensated by introducing the integrator in the present control system. The thickness values y_1, y_2, y_9 and y_{10} are once increased by influence of external heat through thermal conduction along the width of the die. In order to cancel the influence of such external heat, reductions of amounts u_3 to u_8 of heat generated by the heater located outside of the control region are largest, and reductions of amounts u_1, u_2, u_9 and u_{10} generated by the heaters located outside of the control region is smallest.

B2. Second Embodiment of Invention

(a) Relation to First Embodiment of the Invention

[0058] The first embodiment of the invention employs the control systems of the first embodiment of the invention of EP 0608917 as the basic control systems, while the second embodiment of the invention employs the control systems of the second embodiment of the invention of EP 0608917 as basic control systems.

(b) Dead Time

[0059] The thickness gauge measures thickness of film along a locus as shown in Fig. 6. If a position of thickness t_3 is indicated by the point Ⓒ in Fig. 6, the dead time L_2 due to movement of the thickness gauge in the case where calculation is made at the end Ⓐ of film is expressed by a time L_2' corresponding to movement between the points Ⓒ and Ⓐ of Fig. 6.

[0060] On the other hand, when calculation is made at the end Ⓑ of film, the dead time L_2 due to movement of the thickness gauge is expressed by a time L_2'' corresponding to movement between the points Ⓒ' and Ⓑ in Fig. 6. As can be seen from Fig. 6, since the dead time L_2' is generally different from the dead time L_2'', the control system which

controls thickness t_3 to a predetermined value is characterized in that the dead time 1 of the equation (3b) is different depending on whether calculation is made at the end Ⓐor Ⓑof film. That is:
the dead time L_A for the end Ⓐis given by

$$L_A = L_1 + L_2' \tag{9b}$$

the dead time L_B for the end Ⓑis given by

$$L_B = L_1 + L_2'' \tag{10b}$$

Accordingly, the thickness gauge produces an arrival end identification signal for identifying the end Ⓐor Ⓑwhich the thickness gauge has reached.

[0061] The thickness gauge is moved in reciprocating manner along the width of film as shown in Fig. 6 to detect thickness of film and finishes measurement of thickness over the width of film when the thickness gauge has reached the end Ⓐor Ⓑof film. At this time, the calculation is executed and accordingly the execution period of calculation is substantially equal to a time required for movement of the thickness gauge over the width of film and the period is considered to be constant. Thus, the basic control system is a discrete time control system.

(c) Basic Control System

[0062] The state equations (2b) and (3b) are controllable and observable. The relation of the input u(t) and the output y(t) is shown in Fig. 2 from the equations (2b) and (3b). Double line in Fig. 2 indicates vector value. A configuration of the basic control system of the second embodiment is also the same as that of Fig. 3. Double line of Fig. 3 indicates vector value. The configuration of the basic control system shown in Fig. 3 is as follows:

(1) It is assumed that the thickness gauge 11b reaches the end Ⓐor Ⓑof film at the discrete time $t=t_{k+1}$. At this time, a vector consisting of detected values of thickness $y(t_{k+1})=y(k+1)(y_1(k+1)\sim y_5(k+1))$ is obtained through the thickness gauge 11b and sampler 100. At the same time, the thickness gauge produces the arrival end identification signal d indicative of the end which the gauge has reached.

(2) Only thickness $y_3(k+1)$ of a portion of film corresponding to the heater h3, of the film thickness detection vector $y(k+1)$ is supplied to a subtracter 101 which produces thickness deviation $\varepsilon(k+1)=r_3(k+1)-y_3(k+1)$ between the thickness $y_3(k+1)$ and a set value $r_3(k+1)$.

(3) An integrator 102 is supplied with the thickness deviation $\varepsilon(k+1)$ from the subtracter 101 and produces a time-integrated value $X_r(k+1)$ of the thickness deviation. The integrator 102 serves as an external disturbance compensator to compensate the external disturbance varying thickness y_3 by heat generated by the heater and to control thickness y_3 to be identical with a set value.

(4) The operational calculator 103 is supplied with a past time sequence data (herein u(k)) of heat generated by the heater stored in a memory 104 and the film thickness detection value $y(k+1)$ and produces an estimated value $\hat{X}(t_{k+1}-L)=\hat{\omega}(k+1)$ of state variable at time $(t_{k+1}-L)$ before time t_{k+1} by the dead time L defined by the arrival end identification signal d produced from the thickness gauge.

(5) A state shifter 105 is supplied with the output $x_r(k+1)$ of the integrator 102 and the output $\omega(k+1)$ of the operational calculator 103 and multiplies them by a coefficient for shifting the state by the average dead time $\bar{L}$ which is an average value of the dead time L_A (refer to the equation (9b)) in the case where the thickness gauge has reached the end Ⓐand the dead time L_B (refer to the equation (19b)) in the case where the thickness gauge has reached the end Ⓑto obtain a state estimated value at time t_{k+1}.

$$\bar{L} = (L_A + L_B)/2 \tag{11b}$$

From the equations (9b), (10b) and (11b), the dead time $\bar{L}$ is given by

$$\bar{L} = L_1 + (L_2' + L_2'')/2 \tag{12b}$$

$(L_2' + L_2'')$ is substantially equal to a time required for movement of the thickness gauge over the width of film and

accordingly is equal to the execution period t of calculation. Thus, from the equation (12b), the average dead time $\bar{L}$ is given by

$$\bar{L} = L_1 + T/2 \tag{13b}$$

As seen from the equation (13b), the average dead time L is constant irrespective of the end of film which the thickness gauge reaches.

(6) A state prediction device 106 produces state variations for the inputs u(k) from time $(t_{k+1}-\bar{L})$ to time t_{t+1} which are supplied from the memory 104 which stores the past time sequence data of heat generated by the heater by the average dead time in the same manner as the state shifter 105.

(7) An adder 107 is supplied with an output of the state shifter 105 and an output of the stage prediction device 106 and produces as the addition result thereof a state estimated value at time t_{k+1}. Although the operational calculator 103 can not obtain only the state estimated value at time $(t_{k+1}-L)$ due to the dead time L, the state shifter 105 and the state prediction device 106 effect integration operation during the average dead time $\bar{L}$ to obtain the state estimated value at time t_{k+1}. Since the above operation (5), (6) and (7) can remove influence the phase delay due to the average dead time L, thickness control with good response can be effected while maintaining the stability of the control system.

(8) A heat commander 108 multiplies the state estimated value from the adder 107 by the feedback gain to produce a heat command value to the operating terminal device 109. If the operation amount of the operating terminal device 109 is changed, thickness of the film is changed through thickness process 130

(9) The above calculation is made each time a new film thickness detection value y(k+2) is obtained by the sampler 100 when the thickness gauge 11b reaches the opposite end of film at time t_{k+2} and thickness data along the whole width of the film is newly obtained through the dead time 131.

(d) Average Dead Time

[0063] The reason that the average dead time L is used as the integration time in the state shifter 105 and the state prediction device 106 instead of the dead times L_A and L_B is now described.

[0064] If the integration section corresponding to the dead time L_A or L_B different from each other by the calculation for the end Ⓐ or Ⓑ is assumed, the state estimated value at time t_{k+1} is not continuous for each calculation and changes stepwise. When the dead time L_A is larger than the dead time L_B, the state estimated value at the end Ⓐ is larger than the state estimated value at the end Ⓑ and the operation value of the heater defined by multiplying the state estimated value by the feedback gain is also repeatedly varied unevenly. There is a drawback that variation of the operation value is maintained even in the steady state. On the other hand, if the average dead time L is used for the calculation at the ends Ⓐ and Ⓑ in common, there is no state in which the state estimated value is incontinuous at the ends Ⓐ and Ⓑ because of the identical integration section and uneven variation of the operation value in the steady state is removed.

(e) Thickness Control by Combined Basic Control Systems

[0065] The first embodiment of the invention is identical with the second embodiment thereof with the exception that only the basic control systems are different. Combination of the basic control systems is the same. Accordingly, description for thickness control by the combined basic control systems in the first embodiment of the invention can be all applied to the second embodiment. That is, description in B1(h) to (j) is all applied to B2.

(f) Design Example

[0066] An actual example is now described. As a first actual example, an example of design is described in the case where transfer functions $g_1(s)$, $g_2(s)$ and $g_3(s)$ are given by the following equations:

$$g_1(s) = \frac{0.14}{S^3 + 5.5S^2 + 12.5S + 0.25} \tag{14b}$$

$$g_2(s) = \frac{0.003}{S^4 + 6.4S^3 + 13.2S^2 + 1.3S + 0.009} \tag{15b}$$

$$g_3(s) = \frac{0.00005}{S^5 + 6.3S^4 + 13.8S^3 + 1.6S^2 + 0.04S + 0.002} \qquad (16b)$$

The basic control systems (1) to (6) as shown in Fig. 4, ten heaters h1 to h10, and ten points t1 to t10 of thickness corresponding to positions of the heaters are assumed and it is considered that thicknesses y_3 to y_8 are controlled to a predetermined value. $u_i(t)(i=1\text{-}10)$ is variation (watt) of heat generated by the heater, and $y_i(t)(i=1\text{-}10)$ is variation (micron) of thickness of film at the position of the thickness gauge corresponding to the position of the heater. The dead time L_1 due to movement of the film and times L_2' and L_2'' (referred to Fig. 6) required for movement of the thickness gauge from the thickness control point 3 to 8 to the film end assume a value of the following equation and values shown in Table 2.

$L_1 = 26$ seconds

Table 2.

Dead Time L at Thickness Control Points						
Thickness Control Point	3	4	5	6	7	8
Dead Time L_2'(sec)	2.8	3.75	4.7	5.6	6.6	7.5
Dead Time L_2''(sec)	19.7	18.75	17.8	16.9	15.9	15.0
Whole Dead Time L of End (A)(sec) (L_1+L_2)	28.8	29.75	30.7	31.6	32.6	33.5
The same of End (B)	45.7	44.75	43.8	42.9	41.9	41.0

It is assumed that the thickness control point 3 exists at the end Ⓐ of the film as shown in Fig. 6. The control calculation execution period T assumes the following value.

$T = 22.5$ seconds

In order to design the control system, it is necessary to express the relation between the input u(t) and the output y(t) of the equation (1b) and obtain the controllable and observable state equations (2b) and (3b). G(s) constituted of $g_1(s)$, $g_2(s)$ and $g_3(s)$ of the equations (14b) to (16b) can be expressed by an equation of the 77th degree, while the controllable and observable equation has been found to be an equation of the 29th degree. Accordingly, the equations (2b) and (3b) of the 29th degree are obtained from G(s).

(1) Decision of State Feedback Gain Matrix

[0067] The state feedback gain matrix of the basic control system is obtained as a solution of an optimum regulator problem for the state equation extended to the equation of the 30th degree by introducing the integrator for compensation of external disturbance on the basis of the equation (2b). Since the calculation is made every T=22.5 seconds, the state equation of the continuous time system is changed to a discrete state function with the sampling period T=22.5 seconds and a regulator solution is applied. A proper estimation function is employed to obtain the state feedback gain matrix and as a result the following values are obtained as main values for determining the response of the control system as the eigen values of the control system.

0.856, 0.8119, 0.7755, 0.7618

Further, eigen values other than above are not described since the absolute value thereof is small and attenuation is fast. Since all eigen values are within a circle having a radius of 1, stable control can be attained. Since the eigen value having the slowest attenuation is 0.856, the stabilization time Ts can be predicted as about 12 minutes from $(0.856)^{30}$ ≒ 0.01 with definition of control error 1% as follows.

Ts = Tx30 = 22.5x30 sec. = 675 sec. = 11.3 min.

(2) Decision of Feedback Gain of Operational Calculator

[0068] The feedback gain matrix of the operational calculator which estimates the state before time t_{k+1} for calculation execution by the dead time L is obtained for the state equation of the 29th degree and the output equation of the fifth degree. Fig. 14 is a diagram illustrating the discrete time used to transforms the state equation (2b) to the discrete equation in order to obtain the gain matrix of the operational calculation. In Fig. 14, it is assumed that the estimated value $\hat{X}(t_k\text{-}L_B)$ of the state variable at the past time by the dead time L_B has been already obtained in the calculation at the end Ⓑ performed at time t_k. In order to obtain the estimated value $X(t_{k+1}\text{-}L_A)$ of the state variable at the past time by the dead time L_A in the calculation at the end Ⓐ performed at time t_{k+1}, the state equation (2b) must be transformed

to a discrete form with a time difference $(t_{k+1}-L_A)-(t_k-L_B)=t_{k+1}-t_k-L_A+L_B$. The discrete time is $(T-L_A+L_B)$ because of $t_{k+1}-t_k=T$. The discrete time $(T-L_A+L_B)$ for the thickness control point 3 is calculated from $L_A=28.8$ seconds and $L_B=45.7$ seconds in Table 2 as follows:

$$T - L_A + L_B = 39.4 \text{ seconds}$$

For the state equation transformed to the discrete form with 39.4 seconds, a proper evaluation function is employed to obtain the gain matrix of the operational calculation as a solution of an optimum regulator problem. The following values are obtained as main values for determining convergence of the operational calculation as eigen values of the operational calculator for the obtained gain matrix.

0.7743, 0.7743, 0.7743, 0.7743, 0.7743,
0.4484, 0.4484, 0.4484, 0.4484, 0.4484

[0069]   Since eigen values other than above are small and convergence is fast, they are not described. Since all the values are within a circle having a radius of 1, the estimated error can be reduced with lapse of time. Since the eigen value having the slowest attenuation is 0.7743, the time To required for attenuation of the estimated error to an initial 1% can be predicted from $(0.7743)^{18} \fallingdotseq 0.01$ as follows.

$$\text{To} = (T-L_A+L_B) \times 18 = 39.4 \times 18 \text{ sec.} = 709 \text{ sec.}$$

$$= 11.8 \text{ min.}$$

For other thickness control points, the gain matrix of the operational calculation having the stabilization time To of 12 minutes was obtained in the same manner.

(g) Simulation 1

[0070]   Figs. 15 and 16 show an example of simulation result obtained by calculation using the state feedback and the gain of the operational calculation obtained above.

[0071]   Figs. 15 and 16 show variations of thickness and variation of heat generated by the heaters when the set values of thickness y_3 to y_8 are changed stepwise by 5 micron. Fig. 15(a) shows variations of five amounts y_1 to y_5 of thickness (variation of the detected value of the thickness gauge) versus time. Fig. 15(b) shows variations of heat u_1 to u_5 generated by the heaters at this time in the same manner as Fig. 15(a). Fig. 16(a) shows variations of thickness y_6 to y_{10} and Fig. 16(b) shows variations of heat u_6 to u_{10} generated by the heater.

[0072]   Since calculation is made after the execution period of 22.5 seconds of calculation after the set value of thickness has been changed, variation of heat generated by the heater occurs after 22.5 seconds from change of the set value of thickness. An amount of heat generated by the heater is maintained to the same value until 22.5 seconds elapse and the next calculation is made. The calculation is made on the basis of a newly detected value of thickness after 22.5 seconds to change an amount of heat generated by the heater. Accordingly, an amount of heat generated by the heater changes stepwise as shown in Fig. 15 and 16(b).

[0073]   On the other hand, variation of the detected thickness value is detected after the lapse of the dead time L after the amount of heat generated by the heater has been changed after the lapse of 22.5 seconds from the change of the set value. For example, when calculation is made with thickness y_3 for the end Ⓐ shown in Fig. 16, the dead time L is 28.8 seconds from Table 2. That is, variation of thickness is detected after the lapse of 22.5 + 28.8 = 51.3 seconds after the set value of thickness has been changed. Thickness y_3 is exactly changed to a set value as can be seen from Figs. 15 and 16. The heaters h1, h2, h9 and h10 are introduced in consideration of mutual interference to thicknesses y_3 and y_8 and the thicknesses y_1, y_2, y_9 and y_{10} corresponding to the heaters h1, h2, h9 and h10 are not controlled to the set value. On the other hand, variations of heat generated by the heaters u_3 and u_8 at the end in the thickness control region are largest, variations by the heaters u_4 to u_7 located in the center are largest next to the heaters u_3 and u_8, and variations of the heaters u_1, u_2, u_9 and u_{10} located outside of the control region are smallest.

[0074]   As can be seen from Figs. 15 and 16, thickness is controlled to the predetermined value in about 12 minutes after a set value of thickness has been changed, that is, the stabilization time 12 minutes supports a result estimated from the above mentioned eigen value.

(h) Simulation 2

[0075]   A second actual example is now described with reference to Figs. 17 and 18.

[0076] Figs. 17 and 18 shows a control result when external heat of 8 wattage is applied to the heater u_3 to u_8. Fig. 17(a) shows variations of thickness values y_1 to y_5 versus time, and Fig. 17(b) shows variations of heat u_1 to u_5 generated by the heaters versus time. Fig. 18(a) shows variations of thickness values y_6 to y_{10} versus time and Fig. 18(b) shows variations of heat u_6 to u_{10} generated by the heaters versus time.

[0077] As seen in Figs. 17 and 18(a), although the thickness values y_3 to y_8 are once increased by the external heat of the heater u_3 to u_8, the thickness values y_3 to y_8 are returned to the original set value by changing the amounts of heat generated by the heaters u_1 to u_{10} and the stabilization time is about 12 minutes in the same manner as Figs. 15 and 16. It is understood that variation due to the external disturbance is exactly compensated by introducing the integrator in the present control system. The thickness values y_1, y_2, y_9 and y_{10} are once increased by influence of external heat through thermal conduction along the width of the die. In order to cancel the influence of such external heat, reductions of amounts u_3 to u_8 of heat generated by the heater located outside of the control region are largest, and reductions of amounts u_1, u_2, u_9 and u_{10} generated by the heaters located outside of the control region is smallest.

B3. Effects

[0078] As described above, according to the second aspect, the adjusting mechanism for controlling thickness of film includes the die provided with a multiplicity of operating terminal devices disposed along the width of film so that thickness control of a portion of film corresponding to one operating terminal device is effected to compensate external disturbance added to the operating terminal device and its adjacent terminal devices, and there is provided the state prediction function to remove influence due to the dead time for thickness detection so that the basic control systems with good response can be applied to control thickness of film to the predetermined value. Further, the basic control system is applied for each control of thickness of a portion of film corresponding to the operating terminal device so that thickness control over the whole width of film is performed stably.

Claims

1. A method for controlling the thickness of a film (7b), the method comprising the steps of:

    moving a thickness gauge (11b) in a reciprocating manner across the width of the film (7b) to obtain detected film thickness data (y1-yn) at a number of locations across the width of the film (7b),

    supplying the said detected film thickness data (y1-yn) to a thickness data memory (110), whereby the thickness gauge (11b) also supplies an arrival edge identification signal (d) to indicate when the thickness gauge (11b) arrives at an edge of the film (7b),

    supplying, each time the thickness gauge (11b) reaches an end of the film (7b), the said arrival edge identification signal (d) to a distributor (111) as well as to a plurality of basic controllers (112-1 - 112-N), whereby when the distributor (111) is supplied with the arrival end identification signal (d) it reads out the detected thickness data (yl-yn) from the thickness data memory (110) and simultaneously distributes a predetermined distinct set of said detected thickness data (yl-yn) to each basic controller (112-1 - 112-N), whereby each basic controller (112-1 - 112-N) controls the thickness of one particular portion of the width of the film (7b) by means of appropriately arranged heaters (12b) in synchronism with said arrival end identification signal (d),

    supplying each of the said basic controllers (112-1 - 112-N) with data from an operation value memory (115) and identifying the end of the film (7b) which the thickness gauge (11b) has reached on the basis of the arrival end identification signal (d) in order to obtain a correct value of process dead-time (L), and further executing calculation so that a predetermined distinct set of heater command signals (U1-Un) is output by each of the said basic controllers to a corresponding one of a plurality of command value memories (113-1 - 113-N),

    causing a superposition adder (114) to receive the said predetermined distinct set of heater command signals (U1-Un) from each said command value memory (113-1 - 113-N), the superposition adder further being caused to add the said predetermined distinct sets of heater command signals (U1-Un) and to calculate an average value thereof to define a final command value (S) of heat for each heater (12b) which is then stored in the said operation value memory (115),

    whereby, when the thickness gauge (11b) has been moved and has reached the opposite edge of the film (7b), and thus a new arrival end identification signal (d) has been produced, the distributor (111), the basic

controllers (112-1 - 112-N) and the superposition adder (114) are all operated as described above so that all the said sets of heater command signals (U1-Un) are updated.

2. A film thickness controller comprising:

an extruder (1b) for feeding molten plastic to a die (2b);

a plurality of heaters (12b) embedded in the die (2b) for heating the molten plastic so as to control its viscosity;

a thickness gauge (11b) reciprocally moving transversely over a film (7b) for detecting film thickness (y1-yn) at a number of locations across the width of the film,

a control system which compares the detected film thickness (y1-yn) for each location with a predetermined thickness (r) for that location to obtain thickness difference values for each location, and which controls the plurality of heaters (12b) to minimise the said thickness difference values;

wherein the control system comprises:

a thickness data memory (110) for storing the detected film thicknesses (y1-yn), wherein the thickness gauge (11b) also outputs an arrival edge identifying signal (d) to identify when the thickness gauge (11b) has arrived at an edge of the film (7b);

a plurality of basic controllers (112-1 - 112-N), each allocated to the control of one particular portion of the width of the film (7b), said control being carried out by each basic controller (112-1 - 112-N) on the basis of a predetermined distinct set of film thicknesses (y1-yn), received from the thickness data memory (110) via a distributor (111), and on the basis of the said arrival edge identifying signal (d) received from the thickness gauge (11b), whereby each basic controller (112-1 - 112-N) outputs a predetermined distinct set of heater command signals (U1-Un),

wherein each basic controller (112-1 - 112-N) comprises:

a subtracter (101) for obtaining, for each location on the film (7b), the said thickness difference values between the detected film thickness (yl-yn), obtained from the distributor (111), and the predetermined film thickness (r) for that location;

an integrator (102) for time integration of the output of the subtracter (101);

a memory (104) for storing the said heater command signals (U1-Un) output by a heat commander (108) during a process dead-time (L), the dead-time (L) being the sum (L1 + L2) of a dead-time (L1) corresponding to a time required for film movement from the die (2b) to the thickness gauge (11b), and a dead-time (L2) corresponding to a time required for the thickness gauge (11b) to reach an edge of the film (7b);

an operational calculator (103) for obtaining, on the basis of the data in the memory (104), and by using a method of state equations, the state vector at a time before the dead-time (L) of the last data acquisition;

a state shifter (105) for calculation of the state vector at the time of the data acquisition by the thickness gauge (11b) on the basis of the outputs of the integrator (102), the output of the operational calculator (103), and the arrival end identifying signal (d);

a state prediction device (106) for calculation of a change of the state vector in the period of the process dead-time (L) on the basis of the output of the data memory (104);

an adder (107) for adding the output of the state shifter (105) and the output of the state prediction device (106);

whereby the heat commander (108) produces, for each of the heaters (12b), the said heater command signals (U1-Un) on the basis of the output of the adder (107); and

whereby the said control system further comprises:

a plurality of command memories (113-1 - 113-N), each corresponding to one predetermined basic controller (112-1 - 112-N), each for storing a said predetermined distinct set of heater command signals (U1-Un) received from its corresponding basic controller (112-1 - 112-N);

a superposition adder (114) for receiving the said predetermined distinct set of heater command signals (U1-Un) from each said command value memory (113-1 - 113-N), for adding the same and for calculating an average value thereof to define a final command value (S) of heat for each heater (12b).

Patentansprüche

1. Verfahren zur Steuerung der Dicke einer Schicht (7b), wobei das Verfahren die folgenden Schritte aufweist:

Hin- und Herbewegen einer Dicken-Meßeinrichtung (11b) über die Spannweite des Films (7b) zur Ermittlung erfaßter Filmdicken-Daten (yl - yn) bei einer Anzahl von Stellen entlang der Spannweite des Films (7b),

Zuführen der erfaßten Filmdicken-Daten (yl - yn) zu einem Dicken-Datenspeicher (1 10), wobei die Dicken-Meßeinrichtung (11b) ferner ein Ankunfts-Rand-Identifikationssignal (d) liefert, um anzuzeigen, wenn die Dikken-Meßeinrichtung (11b) an den Rand des Films (7b) ankommt,

Zuführen des Ankunfts-Rand-Identifikationssignals (d) zu einem Distributor (111) und einer Vielzahl von Basis-Steuereinrichtungen (112-1 - 112-N) jedesmal sobald die Dicken-Meßeinrichtung (11b) ein Ende des Films (7b) erreicht, wobei, wenn dem Distributor (111) das Ankunfts-Ende-Identifikationssignal (d) zugeführt wird, dieser die erfaßten Dicken-Daten (y1-yn) aus dem Dicken-Datenspeicher (110) ausliest und gleichzeitig einen bestimmten verschiedenartigen Satz der erfaßten Dicken-Daten (yl-yn) an jede Basis-Steuereinrichtung (112-1 - 112-N) verteilt, wobei jede Basis-Steuereinrichtung (112-1 - 112-N) die Dicke eines besonderen Abschnitts der Spannbreite des Films (7b) mittels geeignet angeordneter Erhitzer (12b) synchron zu dem Ankunfts-Ende-Identifikationssignal (d) steuert,

Versorgen jeder der Basis-Steuereinrichtungen (112-1 - 1 12-N) mit Daten von einem Operationswert-Speicher (115) und Identifizieren des Endes des Films (7b), das die Dicken-Meßeinrichtung (11b) erreicht hat, auf der Grundlage des Ankunfts-Ende-Identifikationssignals (d) zur Ermittlung eines richtigen Wertes einer Prozeß-Tod-Zeit (L), und ferner Ausführen der Berechnungen derart, daß ein vorbestimmter verschiedenartiger Satz von Erhitzer-Befehlssignalen (U1-Un) durch jede der Basis-Steuereinrichtungen zu einem entsprechenden Speicher der Vielzahl von Befehlswertspeichern (113-1 - 113-N) abgegeben wird,

Veranlassen eines Überlagerungsaddierers (114) zum Empfang des vorbestimmten verschiedenartigen Satzes von Erhitzer-Befehlssignalen (U1-Un) von jedem der Befehlswertspeicher (113-1 - 113-N), wobei der Überlagerungsaddierer ferner dazu veranlaßt wird, die vorbestimmten verschiedenartigen Sätze von Erhitzer-Befehlssignalen (U1-Un) zu addieren und einen Durchschnittswert von diesen zu berechnen, damit ein letztendlicher Befehlswert (S) der Wärme für jeden Erhitzer (12b) festgelegt wird, der dann in den Operationswert-Speicher (115) abgespeichert wird,

wobei, wenn die Dicken-Meßeinrichtung (11b) bewegt worden ist und den gegenüberliegenden Rand des Films (7b) erreicht hat und somit ein neues Ankunfts-Ende-Identifikationssignal (d) erzeugt worden ist, der Distributor (111), die Basis-Steuereinrichtungen (112-1 - 112-N) und der Überlagerungsaddierer (114) in besagter Weise derart betrieben werden, so daß alle Sätze der Erhitzer-Befehlssignale (U1-Un) erneuert werden.

2. Steuergerät für die Dicke einer Schicht mit:

einem Extruder (1b) zum Zuführen eines geschmolzenen Kunststoffs zu einer Form (2b);

einer Vielzahl von Erhitzungseinrichtungen (12b), die in der Form (2b) eingebettet sind, zum Erwärmen des geschmolzenen Kunststoffs, so daß dessen Viskosität steuerbar ist;

einer Dicken-Meßeinrichtung (11b), die quer über einer Schicht (7b) hin und her bewegbar ist zur Erfassung der Dicke des Films (y1-yn) bei einer Anzahl von Stellen entlang der Spannbreite der Schicht;

einem Steuersystem, das die erfaßte Schichtdicke (y1-yn) für jede Stelle mit einer vorbestimmten Dicke (r) für diese Stelle vergleicht zur Ermittlung von Dicken-Differenzwerten für jede Stelle, und das die Vielzahl von Erhitzern (12b) zur Minimierung der Dicken-Differenzwerte steuert;

wobei das Steuersystem aufweist:

einen Dicken-Datenspeicher (110) zum Abspeichern der erfaßten Schichtdicken (yl-yn), wobei die Dicken-Meßeinrichtung (11b) ferner ein Ankunfts-Rand-Identifikationssignal (d) abgibt, um zu identifizieren, wenn die Dicken-Meßeinrichtung (11b) den Rand der Filmschicht (7b) erreicht hat;

eine Vielzahl von Basis-Steuereinrichtungen (112-1 - 112-N), wobei jede zur Steuerung eines besonderen Abschnitts der Spannbreite der Filmschicht (7b) angeordnet ist, wobei die Steuerung durch jede Basis-Steuereinrichtung (112-1 - 112-N) auf der Grundlage eines vorbestimmten verschiedenartigen Satzes von Filmschicht-Dicken (y1-yn) ausgeführt wird, die von dem Dicken-Datenspeicher (110) über einen Distributor (111) empfangen werden, und auf der Grundlage des Ankunfts-Rand-Identifikationssignals (d), das von der Dicken-Meßeinrichtung (11b) empfangen wird, wobei jede Basis-Steuereinrichtung (112-1 - 112-N) einen vorbestimmten verschiedenartigen Satz von Erhitzer-Befehlssignalen (U1-Un) abgibt,

wobei jeder der Basis-Steuereinrichtungen (112-1 - 1 12-N) aufweist:

eine Subtraktionseinrichtung (101) zur Ermittlung an jeder Stelle der Filmschicht (7b) der Dicken-Differenzwerte zwischen den erfaßten Filmschicht-Dicken (y1-yn), die von dem Distributor (111) erhalten werden, und der vorbestimmten Filmschicht-Dicke (r) für diese Stelle;

eine Integrationseinrichtung (102) für die Zeitintegration des von der Subtraktionseinrichtung (101) abgegebenen Ausgangssignals;

einen Speicher (104) zum Abspeichern der Erhitzer-Befehlssignale (U1-Un), die durch eine Erhitzungs-Befehlseinrichtung (108) während einer Prozeß-Tod-Zeit (L) abgegeben werden, wobei die Tod-Zeit (L) die Summe (L1+L2) einer Tod-Zeit (L1), welche einer Zeitdauer entspricht, die für die Filmschichtbewegung ausgehend von der Form (2b) zu der Dicken-Meßeinrichtung (11b) erforderlich ist, und einer Tod-Zeit (L2) ist, welche einer Zeitdauer entspricht, die die Dicken-Meßeinrichtung (11b) zum Erreichen eines Randes der Filmschicht (7b) braucht;

eine Operationsberechnungseinrichtung (103) zur Ermittlung des Zustandsvektors zu einer Zeit vor der Tod-Zeit (L) der letzten Datenerfassung auf der Grundlage der Daten in dem Speicher (104) und unter Verwendung von Zustandsgleichungen;

eine Zustands-Verschiebungs-Einrichtung (105) zur Berechnung des Zustandsvektors zum Zeitpunkt der Datenerfassung durch die Dicken-Meßeinrichtung (11b) auf der Grundlage der Ausgangssignale der Integrationseinrichtung (102), des Ausgangssignals der Operationsberechnungseinrichtung (103) und des Ankunfts-Ende-Identifikationssignals (d);

eine Zustands-Vorhersage-Einrichtung (106) zur Berechnung einer Veränderung des Zustandsvektors während der Zeitdauer der Prozeß-Tod-Zeit (L) auf der Grundlage des Ausgangssignals des Datenspeichers (104);

eine Addiereinrichtung (107) zur Addition des Ausgangssignals der Zustands-Verschiebungs-Einrichtung (105) und des Ausgangssignals der Zustands-Vorhersage-Einrichtung (106);

wobei die Erhitzungs-Befehlseinrichtung (108) für jeden Erhitzer (12b) die Erhitzungs-Befehlssignale (U1-Un) auf der Grundlage des Ausgangssignals der Addiereinrichtung (107) erzeugt;

und wobei das Steuersystem ferner aufweist:

eine Vielzahl von Befehlsspeichern (113-1 - 113-N), wobei jeder einer vorbestimmten Basis-Steuereinrichtung (112-1 - 112-N) entspricht und zum Abspeichern eines vorbestimmten verschiedenartigen Satzes von Erhitzer-Befehlssignalen (U1-Un) vorgesehen ist, die von der entsprechenden Basis-Steuereinrichtung (112-1 - 1 12-N) empfangen werden;

einen Überlagerungsaddierer (114) zum Empfang des vorbestimmten verschiedenartigen Satzes von Erhit-
zungs-Befehlssignalen (U1-Un) von jedem der Befehlswertspeicher (113-1 - 113-N), für die Addition derselbi-
gen und zur Berechnung eines Durchschnittswertes von diesen, damit ein letztendlicher Befehlswert (S) der
Wärme für jeden Erhitzer (12b) festgelegt wird.

Revendications

1. Procédé pour commander l'épaisseur d'une couche (7b), le procédé comprenant les étapes consistant à :

   déplacer une jauge d'épaisseur (11b) selon un déplacement en va-et-vient sur l'étendue en largeur de la
   couche (7b) pour obtenir des données d'épaisseur de couche détectée (yl-yn) en un nombre d'emplacements
   sur l'étendue en largeur de la couche (7b),
   envoyer les données d'épaisseurs de couche détectées (y1-yn) à une mémoire de données d'épaisseurs
   (110), grâce à quoi la jauge d'épaisseur (11b) envoie également un signal (d) d'identification de bord atteint
   pour indiquer l'instant où la jauge d'épaisseur (llb) atteint un bord de la couche (7b),
   chaque fois que la jauge d'épaisseur (11b) atteint une extrémité de la couche (7b), envoyer le signal (d) d'iden-
   tification de bord atteint à un distributeur (111) ainsi qu'à une pluralité de systèmes de commande de base
   (112-1 - 112-N), grâce à quoi, lorsque le distributeur (111) reçoit le signal (d) d'identification d'extrémité atteinte,
   il lit les données d'épaisseurs détectées (y1-yn) dans la mémoire de données d'épaisseurs (110) et simulta-
   nément distribue un ensemble distinct prédéterminé desdites données d'épaisseurs détectées (y1-yn) à cha-
   que système de commande de base (112-1 - 112-N), ce qui a pour effet que chaque système de commande
   de base (112-1 - 112-N) commande l'épaisseur d'une partie particulière de la largeur de la couche (7b) à l'aide
   d'éléments chauffants (12b) disposés de façon appropriée en synchronisme avec ledit signal (d) d'identification
   d'extrémité atteinte,
   envoyer à chacun desdits systèmes de commande de base (112-1 - 112-N) des données provenant d'une
   mémoire de valeurs d'opérations (115) et identifier l'extrémité de la couche (7b) que la jauge d'épaisseur (11b)
   a atteinte sur la base du signal (d) d'identification d'extrémité atteinte pour obtenir une valeur correcte d'un
   temps mort de traitement (L), et exécuter éventuellement un calcul de telle sorte qu'un ensemble distinct
   prédéterminé de signaux (U1-Un) de commande des éléments chauffants est envoyé par chacun desdits
   systèmes de commande de base à l'une correspondante d'une pluralité de mémoires de valeurs de commande
   (113-1 - 113-N),
   amener un additionneur à superposition (114) à recevoir ledit ensemble distinct prédéterminé de signaux
   (U1-Un) de commande des éléments chauffants en provenance de chacune desdites mémoires de valeurs
   de commande (113-1 - 113-N), l'additionneur à superposition étant en outre amené à additionner lesdits en-
   sembles distincts prédéterminés de signaux (U1-Un) de commande des éléments chauffants et à calculer une
   valeur moyenne de ces signaux pour définir une valeur de commande finale (S) de la chaleur pour chaque
   élément chauffant (12b), qui est alors mémorisée dans ladite mémoire de valeurs d'opération (115),
   ce qui a pour effet que, lorsque la jauge d'épaisseur (11b) s'est déplacée et a atteint le bord opposé de la
   couche (7b) et que par conséquent un nouveau signal (d) d'identification d'extrémité atteinte a été produit, le
   distributeur (111), et le système de commande de base (112-1 - 112-N) et l'additionneur à superposition (114)
   sont tous activés comme décrit précédemment de sorte que la totalité desdits ensembles de signaux (U1-Un)
   de commande des éléments chauffants sont mis à jour.

2. Appareil de commande de l'épaisseur d'une couche, comprenant :

   une extrudeuse (1b) pour amener une matière plastique fondue à une filière (2b) ;
   une pluralité d'éléments chauffants (12b) insérés dans la filière (2b) pour chauffer la matière plastique fondue
   de manière à en régler la viscosité ;
   une jauge d'épaisseur (11b) se déplaçant en va-et-vient transversalement au-dessus d'une couche (7b) pour
   détecter l'épaisseur de couche (y1-yn) en un nombre d'emplacements sur l'étendue en largeur de la couche,
   un système de commande qui compare l'épaisseur de couche détectée (y1-yn) pour chaque emplacement à
   une épaisseur prédéterminée (r) pour cet emplacement pour obtenir des valeurs de différence d'épaisseur
   pour chaque emplacement, et qui commande la pluralité d'éléments chauffants (12b) pour réduire lesdites
   valeurs de différence d'épaisseur ;

   dans lequel le système de commande comprend :

une mémoire (110) de données d'épaisseurs pour mémoriser les épaisseurs de couche détectées (y1-yn), la jauge d'épaisseur (11b) délivrant également un signal (d) d'identification de bord atteint pour identifier le moment où la jauge d'épaisseur (11b) a atteint un bord de la couche (7b) ;

une pluralité de systèmes de commande de base (112-1 - 112-N), dont chacun est affecté à la commande d'une partie particulière de la largeur de la couche (7b), ladite commande étant exécutée par chaque système de commande de base (112-1 - 112-N) sur la base d'un ensemble distinct prédéterminé d'épaisseurs de couche (y1-yn) reçu à partir de la mémoire de données d'épaisseurs (110) par l'intermédiaire d'un distributeur (111), et sur la base dudit signal (d) d'identification de bord atteint reçu de la part de la jauge d'épaisseur (11b), ce qui a pour effet que chaque système de commande de base (112-1 - 112-N) délivre un ensemble distinct prédéterminé de signaux (U1-Un) de commande des éléments chauffants,

dans lequel chaque système de commande de base (112-1 - 112-N) comprend :

un soustracteur (101) pour obtenir, pour chaque emplacement sur la couche (7b), lesdites valeurs de différences d'épaisseurs entre les épaisseurs de couche détectées (y1-yn), obtenues à partir du distributeur (111) et l'épaisseur de couche prédéterminée (r) pour cet emplacement ;

un intégrateur (102) pour l'intégration dans le temps du signal de sortie du soustracteur (101) ;

une mémoire (104) pour mémoriser lesdits signaux (U1-Un) de commande des éléments chauffants, délivrés au dispositif de commande de chaleur (108) pendant un temps mort de traitement (L), le temps mort (L) étant la somme (L1 + L2) d'un temps mort (L1) correspondant à une durée nécessaire pour le déplacement de la couche depuis la filière (2b) jusqu'à la jauge d'épaisseur (11b) et un temps mort (L2) correspondant à une durée requise pour que la jauge d'épaisseur (11b) atteigne un bord de la couche (7b) ;

un calculateur opérationnel (103) pour obtenir, sur la base des données situées dans la mémoire (104) et moyennant l'utilisation d'un procédé d'équations d'état, le vecteur d'état à un instant situé avant le temps mort (L) de la dernière acquisition de données ;

un dispositif de décalage d'état (105) pour calculer le vecteur d'état au moment de l'acquisition des données par la jauge d'épaisseur (11b) sur la base des signaux de sortie de l'intégrateur (102), du signal de sortie du calculateur opérationnel (103) et du signal (d) d'identification d'extrémité atteinte ;

un dispositif de production d'état (106) pour le calcul d'un changement du vecteur d'état pendant la période du temps mort de traitement (L) sur la base du signal de sortie de la mémoire de données (104) ;

un additionneur (107) pour additionner le signal de sortie du dispositif de décalage d'état (105) et le signal de sortie du dispositif de production d'état (106) ;

dans lequel le dispositif de commande de chaleur (108) produit, pour chacun des éléments chauffants (12b), lesdits signaux (U1-Un) de commande de l'élément chauffant sur la base du signal de sortie de l'additionneur (107) ; et

dans lequel ledit système de commande comporte en outre :

une pluralité de mémoires de commande (113-1 - 113-N) dont chacune correspond à un système de commande de base prédéterminé (112-1 - 112-N), servant chacune à mémoriser un ensemble distinct prédéterminé de signaux (U1-Un) de commande des éléments chauffants, reçus de son système de commande de base correspondant (112-1 - 112-N) ;

un additionneur à superposition (114) pour recevoir ledit ensemble distinct prédéterminé de signaux (U1-Un) de commande des éléments chauffants à partir de ladite mémoire de valeurs de commande (113-1 - 113-N) pour additionner ces signaux et pour calculer une valeur moyenne de ces signaux pour définir une valeur de commande finale (S) de la chaleur pour chaque élément chauffant (12b).

FIG. 1

F I G. 2

$$120$$

$$u(t) \Rightarrow$$

$$\dot{x}(t) = Ax(t) + Bu(t)$$

$$y_P = Cx(t)$$

$$y_P(t)$$

$$121$$

$$e^{-SL}$$

$$\rightarrow y(t)$$

F I G. 3

F I G. 4

(a) PROCEDURE (1) $\begin{Bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{Bmatrix}$ → BASIC CONTROL SYSTEM (1) → $\begin{Bmatrix} u_1^{(1)} \\ u_2^{(1)} \\ u_3^{(1)} \\ u_4^{(1)} \\ u_5^{(1)} \end{Bmatrix}$ CONTROL THICKNESS y_3

(b) PROCEDURE (2) $\begin{Bmatrix} y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \end{Bmatrix}$ → BASIC CONTROL SYSTEM (2) → $\begin{Bmatrix} u_2^{(2)} \\ u_3^{(2)} \\ u_4^{(2)} \\ u_5^{(2)} \\ u_6^{(2)} \end{Bmatrix}$ CONTROL THICKNESS y_4

(c) PROCEDURE (3) $\begin{Bmatrix} y_3 \\ y_4 \\ y_5 \\ y_6 \\ y_7 \end{Bmatrix}$ → BASIC CONTROL SYSTEM (3) → $\begin{Bmatrix} u_3^{(3)} \\ u_4^{(3)} \\ u_5^{(3)} \\ u_6^{(3)} \\ u_7^{(3)} \end{Bmatrix}$ CONTROL THICKNESS y_5

(d) PROCEDURE (4) $\begin{Bmatrix} y_4 \\ y_5 \\ y_6 \\ y_7 \\ y_8 \end{Bmatrix}$ → BASIC CONTROL SYSTEM (4) → $\begin{Bmatrix} u_4^{(4)} \\ u_5^{(4)} \\ u_6^{(4)} \\ u_7^{(4)} \\ u_8^{(4)} \end{Bmatrix}$ CONTROL THICKNESS y_6

(e) PROCEDURE (5) $\begin{Bmatrix} y_5 \\ y_6 \\ y_7 \\ y_8 \\ y_9 \end{Bmatrix}$ → BASIC CONTROL SYSTEM (5) → $\begin{Bmatrix} u_5^{(5)} \\ u_6^{(5)} \\ u_7^{(5)} \\ u_8^{(5)} \\ u_9^{(5)} \end{Bmatrix}$ CONTROL THICKNESS y_7

FIG. 5

FIG. 6

LOCUS OF THICKNESS GAUGE

F I G. 7
PRIOR ART

F I G. 8
PRIOR ART
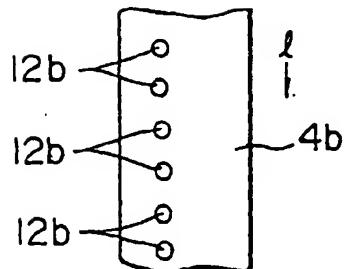
F I G. 9
PRIOR ART
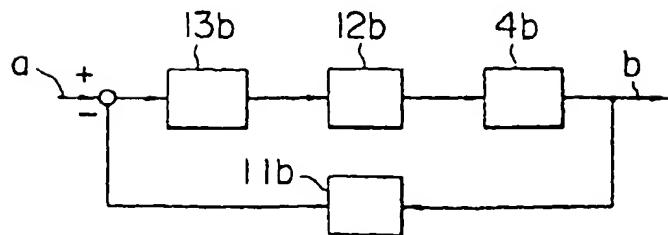
F I G. 10 (a)
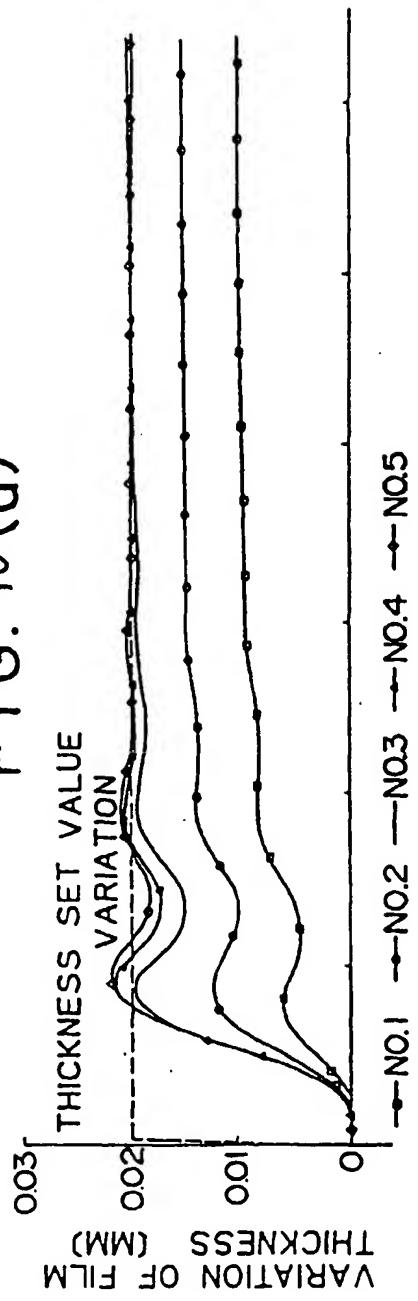
F I G. 10 (b)

FIG. 11 (a)

FIG. 11 (b)

FIG. 12 (a)

VARIATION OF FILM
THICKNESS (MM)

NO.1 NO.2 NO.3 NO.4 NO.5

FIG. 12 (b)

EXTERNAL HEAT
(8.4w)

VARIATION OF HEAT
GENERATED BY HEATER (W)

TIME (SEC)
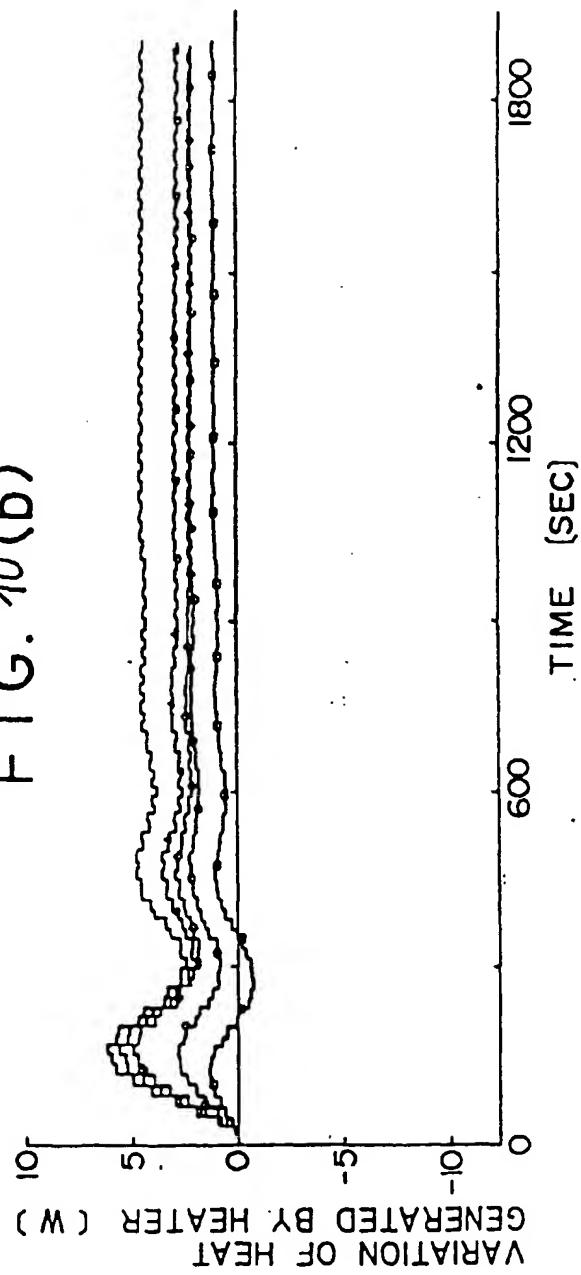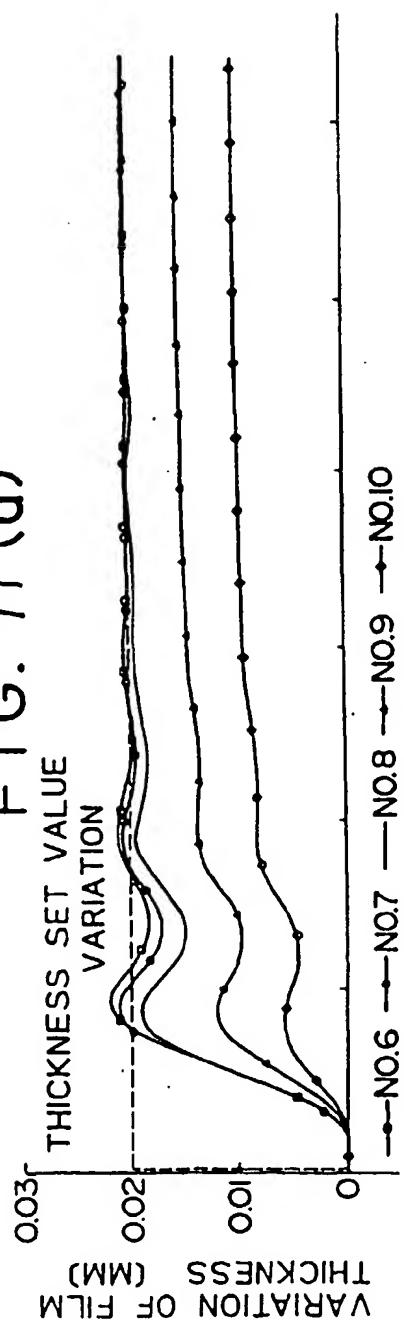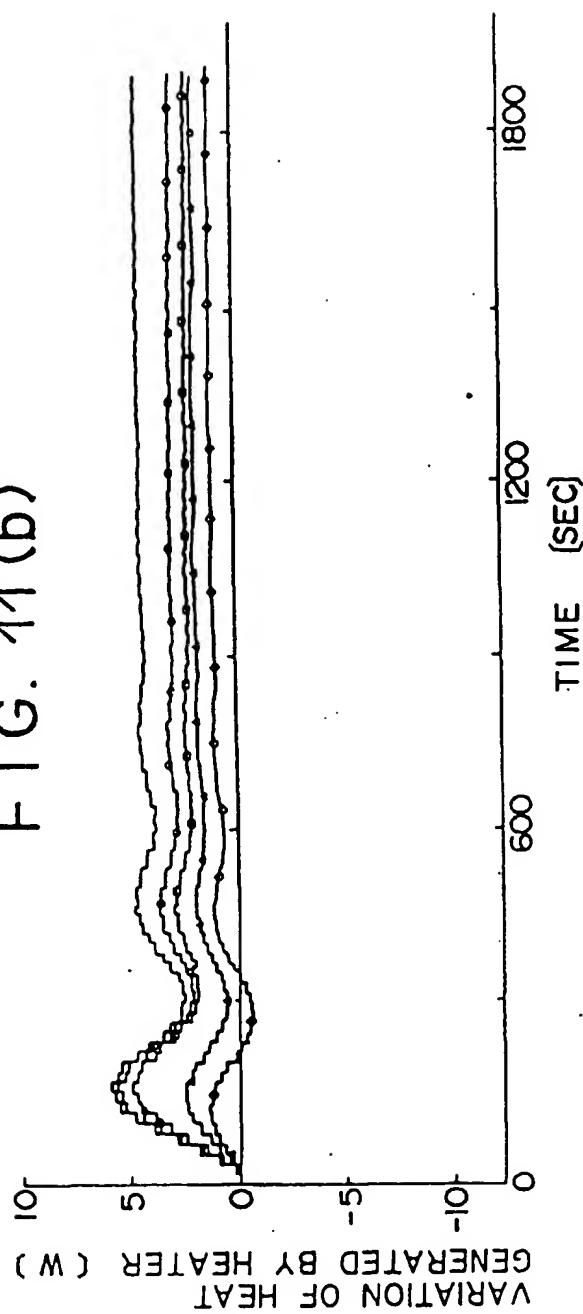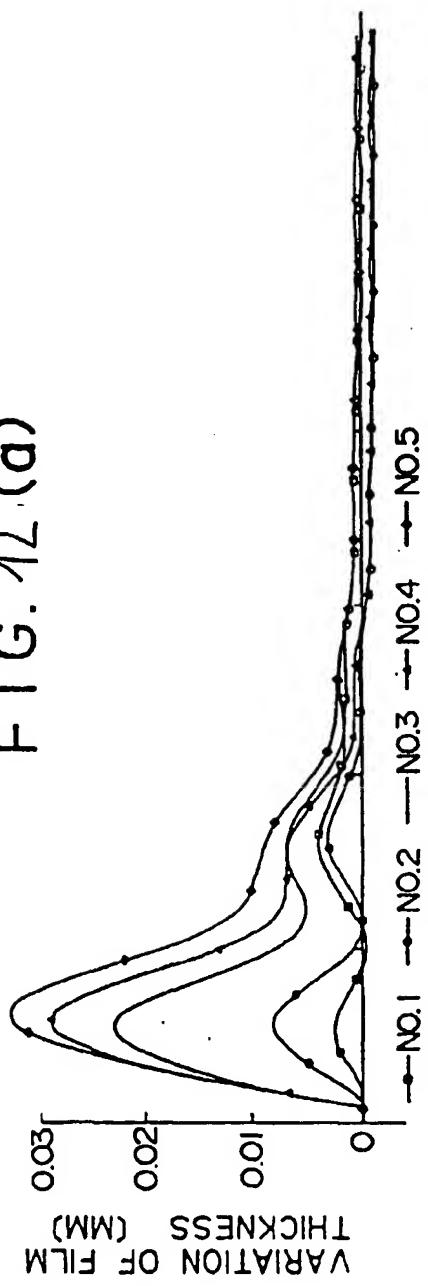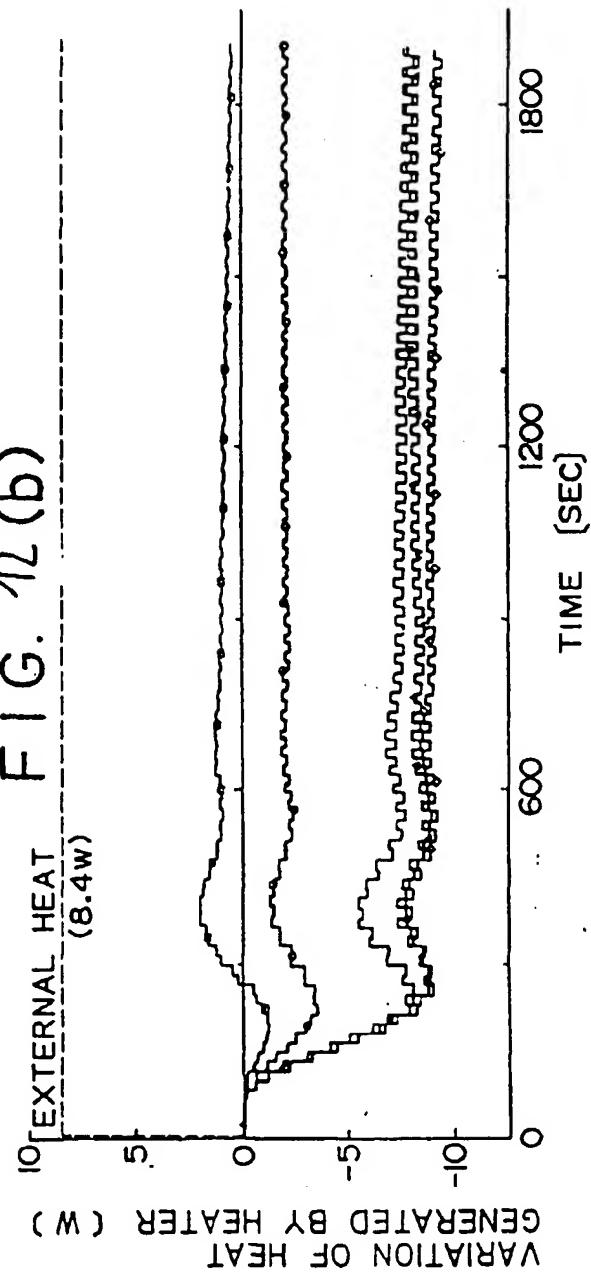
FIG. 13.(a)

FIG. 13.(b)

FIG. 14

F I G. 15(a)

VARIATION OF THICKNESS SET VALUE (5MICRON)

── NO.1 ── NO.2 ── NO.3 ── NO.4 ── NO.5

VARIATION OF FILM
THICKNESS (MM)

F I G. 15(b)

TIME (SEC)

VARIATION OF HEAT
GENERATED BY HEATER (W)

FIG. 16(a)

VARIATION OF THICKNESS SET VALUE (5MICRON)

NO.6 — NO.7 — NO.8 — NO.9 — NO.10

VARIATION OF FILM THICKNESS (MM)

FIG. 16(b)

VARIATION OF HEAT GENERATED BY HEATER (W)

TIME (SEC)

FIG. 17.(a)

VARIATION OF FILM THICKNESS (MM)

NO.1 ·····●····· NO.2 ——— NO.3 ·····●····· NO.4 ·····▲····· NO.5

FIG. 17.(b)

EXTERNAL HEAT (8w)

VARIATION OF HEAT GENERATED BY HEATER (W)

TIME (SEC)